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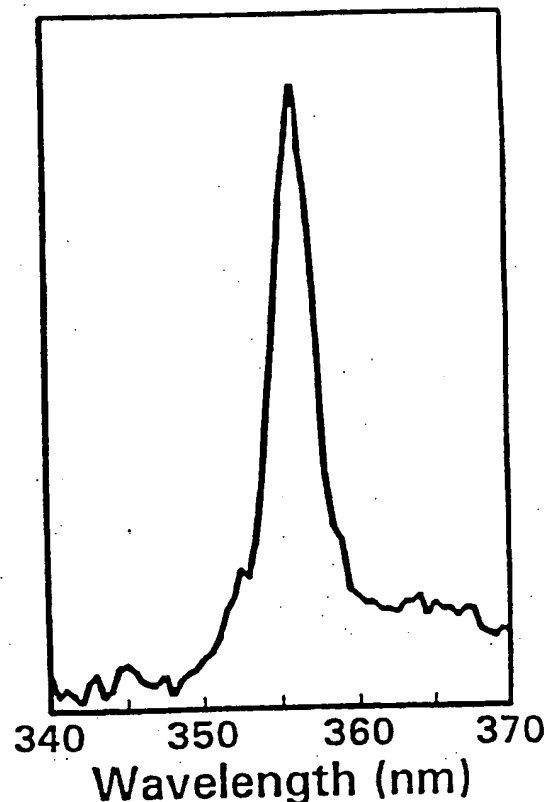
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(21) International Application Number: PCT/US93/05448 (22) International Filing Date: 8 June 1993 (08.06.93) (30) Priority data: 895,350 8 June 1992 (08.06.92) US (71) Applicant: APA OPTICS, INC. [US/US]; 2950 N.E. 84th Lane, Blaine, MN 55434 (US). (72) Inventors: VAN HOVE, James, M. ; 4377 Orion Lane, Eagan, MN 55123 (US). KUZNIA, Jon, N. ; 319 105th Street West, Bloomington, MN 55420 (US). OLSON, Donald, T. ; 2225 North Snelling Avenue, Roseville, MN 55113 (US). KHAN, Muhammad, Asif ; 1958 Oak Knoll Drive, White Bear Lake, MN 55110 (US). BLASIN-GAME, Margaret, C. ; 2662 Scotland Court, Moundsview, MN 55112 (US).	(74) Agent: RAASCH, Kevin, W.; Merchant, Gould, Smith, Edell, Welter & Schmidt, 1000 Norwest Center, 55 East Fifth Street, St. Paul, MN 55101 (US). (81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: HIGH RESPONSIVITY ULTRAVIOLET GALLIUM NITRIDE DETECTOR

(57) Abstract

The invention is an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ultraviolet detector with extremely high responsivity at over 200 to 365 nanometers and a very sharp long wavelength cutoff. The active layer for the sensors is a single crystal $\text{Al}_x\text{Ga}_{1-x}\text{N}$ preferably deposited over a basal plane sapphire substrate using a switched atomic layer epitaxy process.

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HIGH RESPONSIVITY ULTRAVIOLET GALLIUM NITRIDE DETECTOR**Field of the Invention**

The invention generally relates to aluminum gallium
5 nitride ultraviolet detectors. More specifically, the
invention relates to ultraviolet aluminum gallium
nitride detectors formed through a switched atomic layer
epitaxy process.

Background of the Invention

10 $\text{Al}_x\text{Ga}_{1-x}\text{N}$ is a compound semiconductor that is ideally
suited for devices in the visible and the ultraviolet
parts of the spectrum. It's band gap is tunable from
365 nanometers (at $x = 0$) to 200 nanometers (at $x = 1$)
and is direct over the entire alloy composition. This
15 makes the material ideally suited for intrinsic
ultraviolet sensors with responsivities sharply peaked
at a wavelength corresponding to the band edge. Such
sensors have potential commercial applications in the
areas of flame safeguard and fire control.

20 Ultraviolet detectors and, specifically, detectors
of gallium nitride are well known in the art. For
example, Khan et al, U.S. Patent Nos. 4,614,961 and
4,616,248, disclose gallium nitride devices. One device
is an ultraviolet detector comprising a sapphire base,
25 an aluminum nitride matrix matching layer, and an
aluminum gallium nitride active layer. However, made by
conventional metal organic chemical vapor deposition
(MOCVD), the disclosed device has a peak sensor
responsivity at 365 nanometers. The device generally
30 does not provide a broad response across the expanse of
the ultraviolet range.

Others have deposited gallium nitride layers over
basal plane sapphire substrates using metal organic
chemical vapor deposition; see Khan et al, Applied
35 Physics Letters, 58, 526 (1991); Amano et al, Japanese
Journal of Applied Physics, 29, L205 (1990); and
Nakamura et al, Applied Physics Letters, 58, 2021
(1991).

The deposition of various aluminum gallium nitride

layers in various temperature environments has also been well documented, see Khan et al, Applied Physics Letters, 58, 1515 (1991); Khan et al Applied Physics Letters, 58, 2408 (1991); Khan et al, Applied Physics Letters, 60 (11), 1366 (1992); and Khan et al, Applied Physics Letters, 56, 1257 (1990).

However, no prior art gallium nitride ultraviolet device has provided a detector having the level or range of responsivity necessary to provide sensitivity over the broad ultraviolet range while still avoiding interferences created by visible and infrared wavelengths.

Summary of the Invention

In accordance with a first aspect of the invention, there is provided an ultraviolet detector having a single crystal substrate and a single crystal active layer of aluminum gallium nitride ($\text{Al}_x\text{Ga}_{1-x}\text{N}$ wherein $x = 0$ to 1) wherein the ultraviolet detector has a peak sensor responsivity at 365 nanometers which is 0.2×10^6 amps per watt (when $x = 0$) and a substantially constant responsivity for ultraviolet wavelengths ranging from about 200 to 365 nanometers.

In accordance with a second aspect of the invention, there is provided an ultraviolet detector having a single crystal substrate, a matrix layer deposited over the single crystal substrate, and an active layer deposited over the matrix layer, said active layer comprising single crystal aluminum gallium nitride ($\text{Al}_x\text{Ga}_{1-x}\text{N}$ wherein $x = 0$ to 1) wherein the single crystal aluminum gallium nitride active layer is deposited through atomic layer epitaxy.

Preferably, the invention also comprises a metallizing layer which serves as an electrode deposited over the single crystal AlGaN layer. Using an interdigitated electrode pattern with a 10 micron spacing deposited over the AlGaN, the sensor responsivity at 365 nanometers of the claimed detector

may be 0.2×10^6 A/W with a bias of 5 volts when the molar concentration of Al is 0 mol-%. The claimed detector has a responsivity which is nearly constant for wavelengths from 200 to 365 nanometers and it drops by three orders of magnitude by 375 nanometers (within 10 nanometers of the band edge).

Brief Description of the Drawings

FIGURES 1A and 1B are a schematic depiction of two embodiments of the ultraviolet detector of the invention.

FIGURES 2A and 2B are graphical depictions of the optical transmission and photoluminescence of the detector of the invention compared to prior art detectors.

FIGURE 3 is a top plan view of the detector shown in Figs. 1A and 1B.

FIGURE 4A is a graphical depiction of the spectral responsivity of the ultraviolet detector of the invention.

FIGURE 4B is a graphical depiction of the variance in band edge with variation in Al content in the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ active layer.

FIGURE 4C is a graphical depiction of the optical transmission versus wavelength for several detectors each having a different Al molar concentration.

FIGURE 5 is a graphical depiction of the detector of the invention compared to conventional silicon detectors.

FIGURE 6 is a graphical depiction of the photoresponse time of the ultraviolet detector in accordance with the invention.

FIGURE 7 is a top plan view of a device comprising the detector of the invention.

FIGURE 8 is a perspective view of the device shown in Fig. 7.

Detailed Description of the Invention

The invention comprises an ultraviolet aluminum

gallium nitride detector. The detector generally has two layers including a substrate layer and an aluminum gallium nitride layer. Preferably, the detector may also comprise a crystal match or matrix layer between
5 the substrate and the active aluminum gallium nitride layer.

The AlGaN Ultraviolet Detector

Referring to the drawings wherein like numerals represent like parts throughout several views, there is
10 generally shown a AlGaN ultraviolet (UV) detector in Figs. 1A and 1B. In its broadest scope the UV detector of the invention can be seen in Fig. 1A. In this instance the detector comprises a single crystal substrate 1, a matrix layer 3, the single crystal AlGaN
15 active layer 5, and a metallization layer 7 which serves as an electrode for the device. In a more preferred aspect (Fig. 1B), the device comprises a preliminary layer of AlGaN 4 deposited over the matrix layer 3 to function as a seed for the AlGaN active layer 5.

20 Generally, the first layer of the ultraviolet detector is a substrate 1. The substrate functions as a seed for the growth of further layers of the detector as well as a physical support for the detector. Any number of compositions may be used including gallium arsenide,
25 silicon, silicon carbide, zinc oxide, magnesium oxide, germanium, and spinnel quartz among others. Preferably, sapphire, and most specifically, single crystal basal plane sapphire is used as the substrate. Basal plane sapphire is commercially available in single crystal
30 form and serves well as a template for the growth of further layers of the detector. Further, basal plane sapphire is generally transparent to ultraviolet energy. Basal plane sapphire is commercially available through any number of channels.

35 In order to ease the lattice mismatch between single crystal aluminum gallium nitride and the substrate and increase device quality, the ultraviolet detector of the

invention may also comprise an intermediate matrix layer 3. Generally, any number of chemical compositions may be used for such a layer consistent with the function of this layer such as gallium nitride, boron nitride, zinc oxide, magnesium oxide and aluminum nitride, or mixtures thereof among others.

A preliminary layer of aluminum gallium nitride may then be deposited over the substrate 1 and, if present, matrix layer 3. This aluminum gallium nitride layer 4 (Fig. 1B) serves as a substrate for the active single crystal aluminum gallium nitride layer 5 which is later deposited by atomic layer epitaxy. Generally, the aluminum gallium nitride 4 layer may range in thickness generally from about 100 Å to 1000 Å, preferably from about 400 Å to about 600 Å, and most preferably is about 500 Å thick.

The ultraviolet detector of the invention also comprises an aluminum gallium nitride active layer 5. The function of this aluminum gallium nitride active layer is to absorb and collect ultraviolet signals at a high responsivity rate. Preferably, the aluminum gallium nitride layer is single crystal and from about 4000 Å to about 20,000 Å, preferably from about 4000 Å to 10,000 Å, and most preferably about 5000 Å. If the single crystal active aluminum gallium nitride layer is too thin, it will not absorb all the ultraviolet signals incident on the detector. Further, if the aluminum gallium nitride single crystal active layer is too thick, the detector will be unable to collect enough ultraviolet energy to drive or create a response.

In one preferred aspect, the invention comprises a 0.8 micron thick active layer of GaN deposited over a 0.1 micron thick AlN matrix layer 3. Prior to detector fabrication, the epilayer structure was characterized for it's optical transmission and photoluminescence.

In Fig. 2A, the optical transmissivity of the atomic layer epitaxy (ALE) material is comparable to MOCVD

material. In Fig. 2B, the photoluminescence versus wavelength spectrum from atomic layer epitaxy GaN layer shows excellent responsivity by the peak with narrow peak half-width.

5 The UV detector of the invention may also comprise an electrode system 7 (Figs. 1A, 1B and 3). The electrode system serves to sense changes in the AlGaIn active layer 5 created by the UV energy, incident to the detector, and transmit these changes to a sensing
10 circuit. Generally, any number of materials may be used consistent with these functions. One means of defining an electrode system is through conventional metallization and photolithography processes. Metals used for the electrode include aluminum, tungsten,
15 silver, copper, gold, titanium and any number of other conductive metals. One preferred combination comprises an initial layer of titanium followed by gold patterned as interdigitated fingers (Fig. 3).

Using photolithography procedures, the
20 interdigitated electrodes may be formed on the epilayers, Fig. 3. Generally, a liftoff process may be used to form 5000 Å thick gold electrodes. Preferably, the fabricated detector structure may occupy an area of 0.75 mm² and the interdigitated electrodes may be formed
25 3 microns wide, 1 mm long and with 10 micron spacing.

By measurement of the current voltage characteristics of the device with the intensity of the source normalized to allow for the varying emission intensity at different wavelengths, spectral
30 responsivity data for a single (GaN) detector element may be seen in Fig. 4. As seen, the spectral responsivity is beyond the signal detection limit for wavelengths in excess of 375 nanometers. It reaches its peak value at 360 nanometers (band gap energy as seen in
35 Fig. 2A) and then remains nearly constant down to 200 nanometers.

By varying aluminum concentration in the active

layer 5 (x can range from 0 to 1), the band edge may be varied across the UV range. As seen in Fig. 4B, an aluminum concentration of 0 mole-% provides a band edge of about 365 nm. Meanwhile, an aluminum concentration of 1.0 mole-% provides a band edge of 200 nm.

Figure 4C illustrates the ability of AlGaN active layer 5 devices to provide varying band edge positioning across the UV spectrum.

Detector Fabrication Process

10 In fabricating the detector of the invention, a sapphire substrate 1 may be placed on a SiC coated graphite susceptor and heated with rf induction. The matrix layer 3 may then be grown by MOCVD or ALE.

15 The matrix layer 3 assists in providing the sharp band gap cutoff by reducing the crystal mismatch with the active layer 5. It is believed that mismatch leads to crystal structure defects. These crystal structure defects may be visualized or perceived as holes, voids, or openings between the various crystals. The creation of openings between the matrix layer 3 and the active layer 5 results in a flow of electrons to the active layer 5 making this layer conductive. Conductivity in the active layer 5 leads to a greater volume of interference and noise and a rougher band gap cutoff.

25 Preferably, the matrix layer comprises aluminum nitride grown in two stages. The first stage is the growth of an amorphous layer and the second stage is the growth of a single crystal layer. Deposition of the subsequent active layer 5 results in a crystallization of the matrix layer 3, transforming the matrix layer to single crystal. Generally, this matrix layer may be grown to a thickness ranging from about 800 Å to 1700 Å.

30 Preferably, the matrix layer 3 is deposited in a two part deposition process. In the first step of the deposition process an aluminum nitride layer 3A (See Fig. 1A) ranging in thickness from 300 Å to 700 Å, and preferably 500 Å is deposited at 600°C in amorphous form

by MOCVD.

The second phase of the matrix layer, 3B (See also Fig. 1A) is generally deposited in single crystal form a thickness ranging from 500 Å to about 1000 Å, and
5 preferably about 700 Å. This deposition is completed at temperatures ranging from 950°C to about 1080°C and preferably about 1040°C. by MOCVD.

Once the AlN layer is grown, a further seed layer 4 of aluminum gallium nitride may be grown. In practice,
10 this gallium nitride layer may be deposited through standard MOCVD processes at 76 torr pressure and at temperatures ranging from about 950°C to 1080°C and preferably about 1040°C.

Generally, the active aluminum gallium nitride layer
15 5 is grown in single crystal through atomic layer epitaxy. The growth temperature generally ranges from about 800°C and 1000°C and preferably from about 850 to 950°C with a growth time which may span up to or over two hours. The growth temperature may be monitored by a
20 thermocouple inserted in the susceptor.

Source gases for gallium include any number of common gallium sources such as trimethyl or triethylgallium. Other source gases include triethylaluminum and for nitrogen, any number of
25 nitrogenous sources including ammonia. Carrier gases may comprise any number of inert gases such as argon and hydrogen. Hydrogen is preferred as it is readily commercially available and generally clean. Growth pressures may range from about 50 torr to 200 torr, and
30 preferably 100 torr.

Preferably, the deposition system is capable of switched operation under computer control. In this mode, the precursors may be introduced in the growth chamber in a cyclic fashion with an adjustable sweepout
35 time between the precursor pulses. The system preferably also allows for a simultaneous introduction of the precursors. One means of using atomic layer

epitaxy is to grow the aluminum gallium nitride through a series of pulses or using a switched deposition process. In each of the pulses, lasting approximately one second, a different gas is flowed into the chamber.

5 For example, in the first pulse, triethylgallium may be flowed into the chamber. In the second pulse, only the carrier gas, for example hydrogen, is flowed into the chamber. In the third pulse, the nitrogenous source, for example ammonia, may be flowed into the
10 chamber. In the fourth pulse, again only an evacuating flow of hydrogen is flowed into the chamber. In the fifth pulse, an aluminum species may be flowed into the chamber. In the sixth pulse, the carrier gas is then used to evacuate the chamber. In the seventh pulse, the
15 nitrogenous source is then introduced into the chamber. In the eighth pulse, the chamber is then evacuated once again. Films of varying aluminum concentration may be deposited by varying the order and number of pulses for each respective gas species.

20 Preferably, the sequence of steps may be continued over several thousand times resulting in a atomic layer epitaxy process which takes over two hours. As one of skill in the art would expect, variance or extension of this growth period may increase the chemical nature and
25 thickness of the active aluminum gallium nitride single crystal layer.

In completion of the atomic layer epitaxy process, the temperature within the reaction chamber is lowered to range from about 300°C to 400°C and held at that
30 temperature for five minutes in a nitrogen flow.

Detector fabrication is completed by covering the active aluminum gallium nitride layer with a photolithographic layer and developing that layer to a pattern such as that shown in Fig. 3. The
35 photolithographic coated upper surface of the active single crystal aluminum gallium nitride layer is then metallized and then the developed photoresist is

stripped from the upper surface of the aluminum gallium nitride layer 5, also stripping certain aspects of metallization over the photoresist. The resulting pattern (Fig. 3) acts as a receptor 7 for the ultraviolet detector. One metallization system Applicants have found preferable includes 500 Å of titanium followed by the deposition of 1500 Å of gold.

The detector may then be tested by means known to those of skill in the art.

10 Working Examples

Applicants now provide working examples which although useful in understanding and demonstrating the device of the invention, should not be construed as limiting of the invention.

15 Working Example 1

An investigation of photoresponse was undertaken for GaN detectors having the 10 μm wide x 20 μm spaced interdigitated finger mask. Interdigitated fingers with 500 Å of titanium and a 2000 Å of gold were deposited on the GaN. The detectors produced excellent results. The fingers were brought to 200 V DC with little leakage current. The detector had an extremely sharp response starting near the band edge of 365 nm. Dies located in the center of the detector are more conductive. However they still have excellent photoresponse. The sample was all sensitive to a cigarette lighter and propane torch at 3 ft. The bias conditions were 200 V DC.

Working Example 2

A UV detector comprising an ALE GaN layer was grown at 150 torr. The films morphology was very grainy. However the film had excellent optical properties. The sample may well be made up of small crystallites of high quality GaN.

As a means of cutting the wafer, a diamond saw was used to cleave the wafer into individual dies.

The detectivity (amps/watt) was measured for the detector as a function of field strength over the

spectral range of 320-400 nm using a D.C. power supply of 0-200 volts, an ammeter, and a UV radiation source incident to the detector.

An ammeter was used to measure the detector current at a given wavelength over the range of 320-400 nm. The detectivity of the detector was then determined by dividing the measured current by the total wattage. A small correction was performed since all measured light did not hit the detector. The area of the detector was known and the area of the input light was known and ratioed out. Analysis showed that there was no difference between peak dropoff as a function of voltage.

Four trials were run in each instance detectivity dropped two to three orders of magnitude around 370 nm.

Working Example 3

The detectors 10 of Example 1 were repackaged and detectivity was remeasured. A 4 pin canister (Figs. 7 and 8) was used to mount the detector 10. The canister top was filed out to allow light input. The dual detector was cut from the die of Working Example 1 by scribing the back with a carbide steel scribe and placing the cut between two protector slides and lightly tapping. The metal fingers were protected during scribing by a coating of photoresist baked on for 45 minutes at 95°C.

Since the canister 20 was metallic, a piece of glass was bonded onto the pedestal with UV epoxy. The detector was then bonded to the glass with UV epoxy. Wires were attached to the connector wires by attachment to intermediate pads positioned on the glass. A wire was bonded to the pad and ultimately connected to the bonding post. Finally the cap was sealed on with epoxy.

The time response of the UV detector of Example 1 was then measured by pulsing the detector with a nitrogen laser and triggering the scope with the silicon photodiode. The photo-time response appeared to

comprise two time constants, one at 1.0 ms and the other on the order of seconds. The laser was adjusted such that at 10 Hz a 10V DC bias existed on the 1 Mega ohm resistor. The rest of the voltage was an AC signal with
 5 about a 10 ms time constant.

Working Example 4

Another wafer of AlGaIn detectors was grown using the method of Example 1. Four samples were cleaved with a 5:5:5:1 minute hot rinse with trichloroethane, acetone,
 10 methanol, and propanol. The samples were air dried following the propanol rinse. Approximately 500 Å of titanium was then deposited followed by a 2000 Å of Au. The UV response of the detectors was then measured using a black light excitation source.

15	SAMPLE	DIE	V(Bias)	I(Dark) (μ Amps)	I(Photo) (μ Amps)	Response (Seconds)
	A	1	200	0.6	160	3-4
	A	2	200	2	>200	1-2
20	A	3	200	2	>100	1-2
	B	1	200	10	60	3
	B	2	200	10	30	3-4
	B	3	200	10	30	3-4
	B	4	200	10	20	3-4
25	C	1	200	10	50	1
	C	2	200	10	50	1-2
	C	3	200	10	>>200	Fast*
	D	1	3	1	>>200	10
	D	2	18	1	>>200	10
30	D	3	5	10	>>200	5
	E	1	200	20	>200	Fast*
	E	2	200	15	>200	Fast*
	E	3	200	10	> 0.5	1
	E	4	200	10	>200	Fast*
35	E	5	200	10	>200	Fast*
	E	6	200	10	>200	Fast*

*Less than < 1 second.

Working Example 5

40 Using the detector of Working Example 4, detector response was measured using a silicon diode and a spectrometer. The detector of Working Example 4 has a photoresponse similar to that of the detector of Working Example 1. The response dropped 4 orders of magnitude
 45 between 365 nm and 370 nm.

Working Example 6

The peak responsivity of the invention was compared to that from a calibrated silicon detector at a wavelength of 360 nanometers. The silicon detector had an area of 0.95 cm^2 as compared to 0.37 mm^2 as the exposed area for the GaN detector. Fig. 5 shows the plot of the photosignal measured on the two detectors for the same incident power. Note, for these measurements the GaN detector had a bias of 5 Volts and a 10 Hz signal was used for each case. As seen the responsivity of the GaN detector is fairly linear over a large dynamic range. Scaling the photocurrent to account for the detector areas, we estimate the peak responsivity of the GaN detector to be around $0.2 \times 10^6 \text{ A/watt}$. Assuming a quantum efficiency of 0.8 (same as the Si detector) this translates to a gain of around $2 \times 10^6 \text{ A/W}$.

We also measured the response time of our detectors by using a pulsed UV source, Fig. 6. The time resolved photosignal was measured using an oscilloscope. Fig. 6 is a plot of the signal which shows the response time to be 1 ms.

The above discussion, examples and embodiments illustrate our current understanding of the invention. However, since many variations of the invention can be made without departing from the spirit and scope of the invention, the invention resides wholly in the claims hereafter appended.

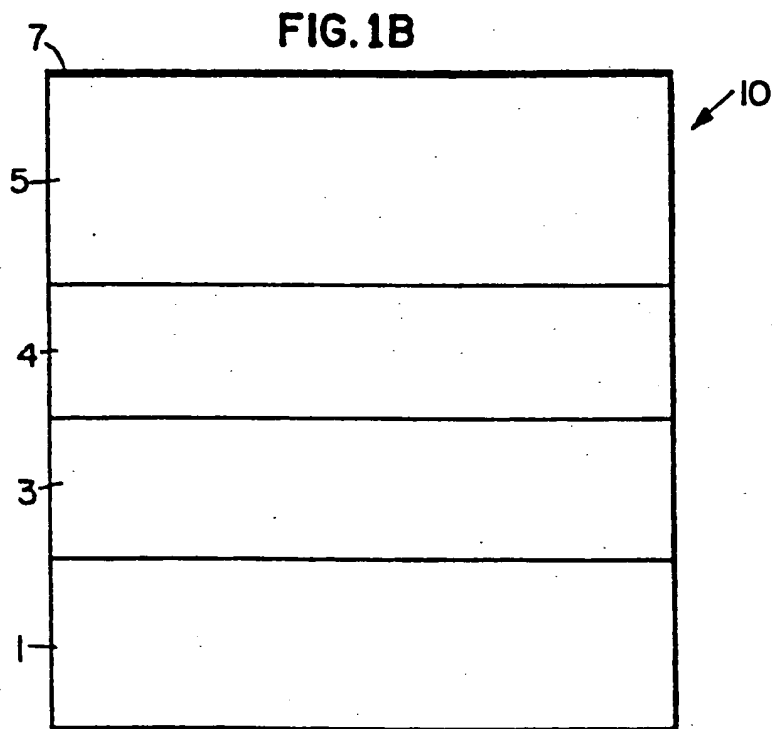
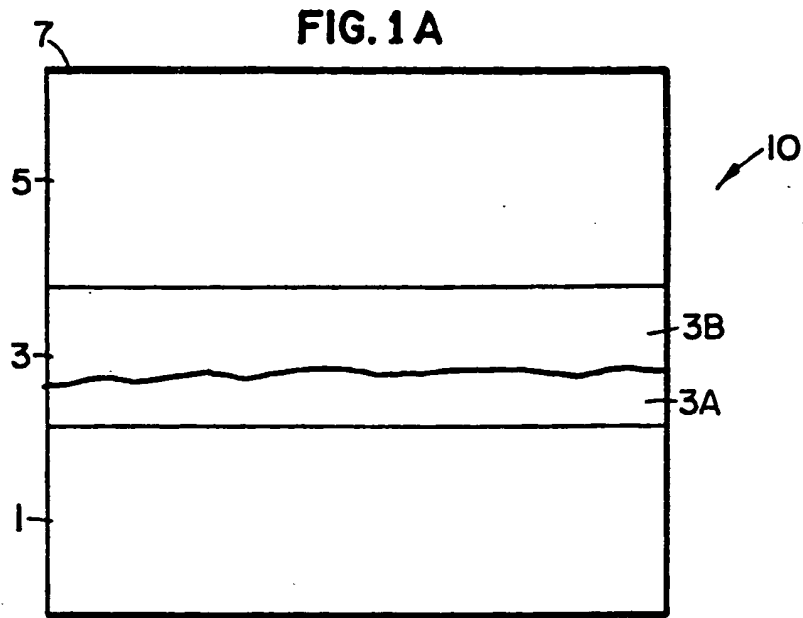
WE CLAIM AS OUR INVENTION:

1. An ultraviolet detector comprising:
 - (a) a single crystal substrate; and
 - (b) a single crystal active layer deposited
5 over said substrate, said single crystal active layer comprising aluminum gallium nitride wherein said ultraviolet detector has a peak sensor responsivity at 365 nanometers which is 0.2×10^6 amps per watt and a substantially constant
10 responsivity for ultraviolet wavelengths ranging from about 200 to 365 nanometers.
2. The detector of claim 1 wherein said active layer has a thickness ranging from about 4000 Å to 20,000 Å.
- 15 3. The detector of claim 1 wherein said substrate comprises basal plane sapphire.
4. The detector of claim 1 comprising an aluminum nitride layer deposited between said substrate and said active layer.
- 20 5. The detector of claim 4 comprising an aluminum gallium nitride layer deposited between said aluminum nitride layer and said active layer, said aluminum gallium nitride layer deposited by metal organic chemical vapor deposition.
- 25 6. An ultraviolet detector comprising:
 - (a) a single crystal substrate;
 - (b) a matrix layer deposited over said single crystal substrate; and
 - (c) an active layer deposited over said matrix
30 layer, said active layer comprising single crystal aluminum gallium nitride wherein said single crystal aluminum gallium nitride active layer is deposited through atomic layer epitaxy.
- 35 7. The detector of claim 6 wherein said active layer has a thickness ranging from about 4000 Å to 20,000 Å.

8. The detector of claim 6 wherein said substrate comprises basal plane sapphire.

9. The detector of claim 6 wherein said matrix
5 layer comprises aluminum nitride deposited between said substrate and said active layer.

10. The detector of claim 6 comprising an aluminum gallium nitride layer deposited between said aluminum nitride layer and said active layer, said aluminum
10 gallium nitride layer deposited by metal organic chemical vapor deposition.



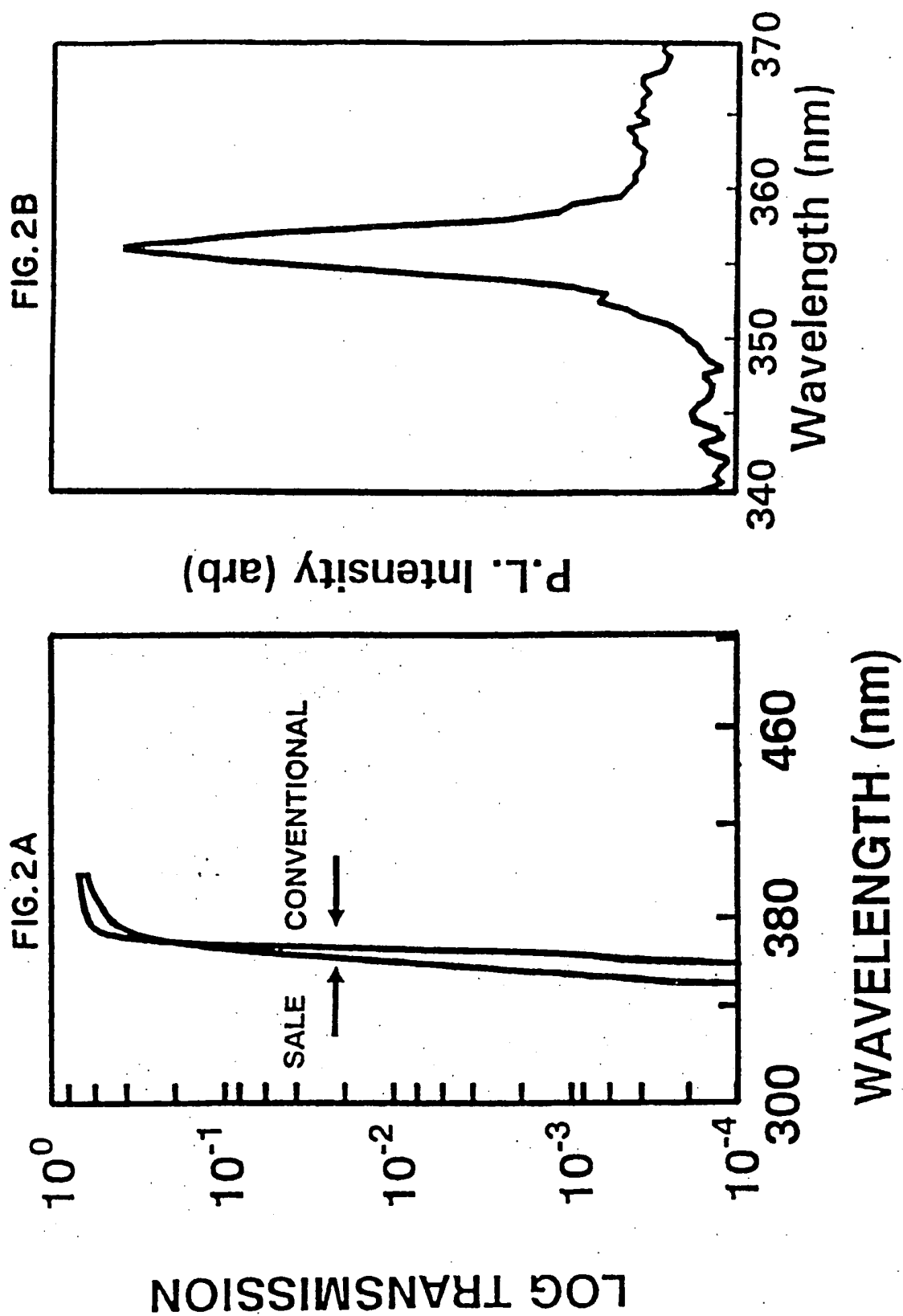
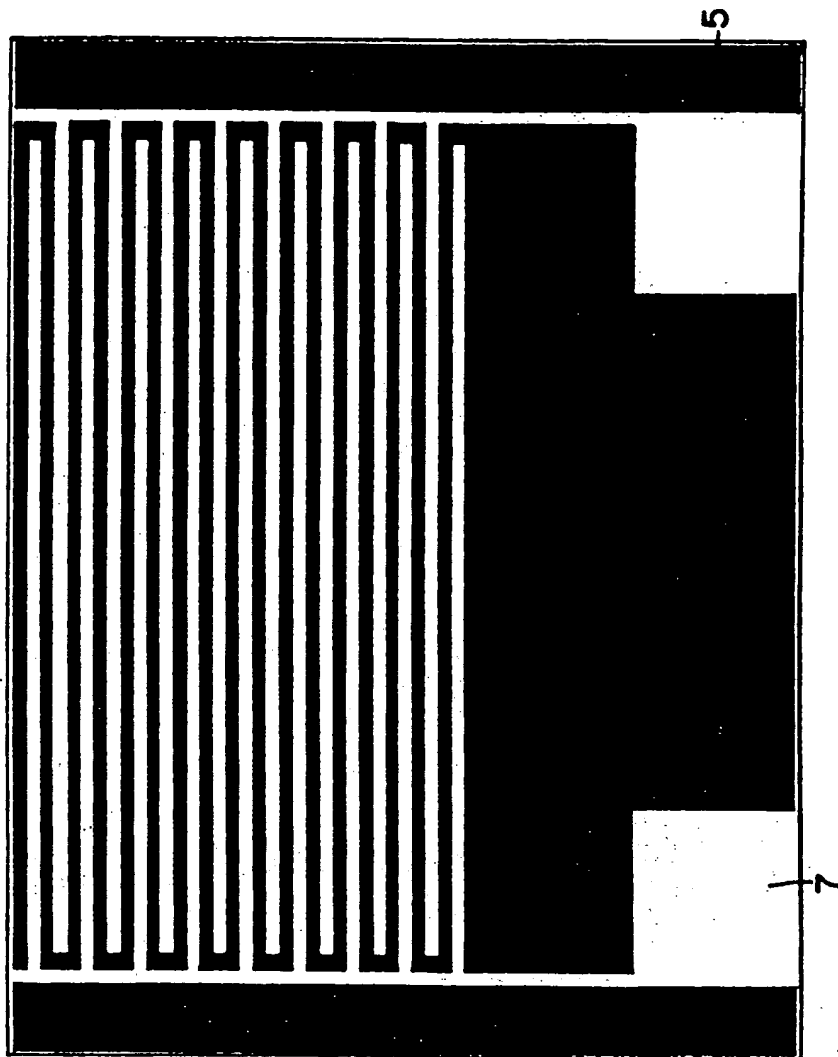
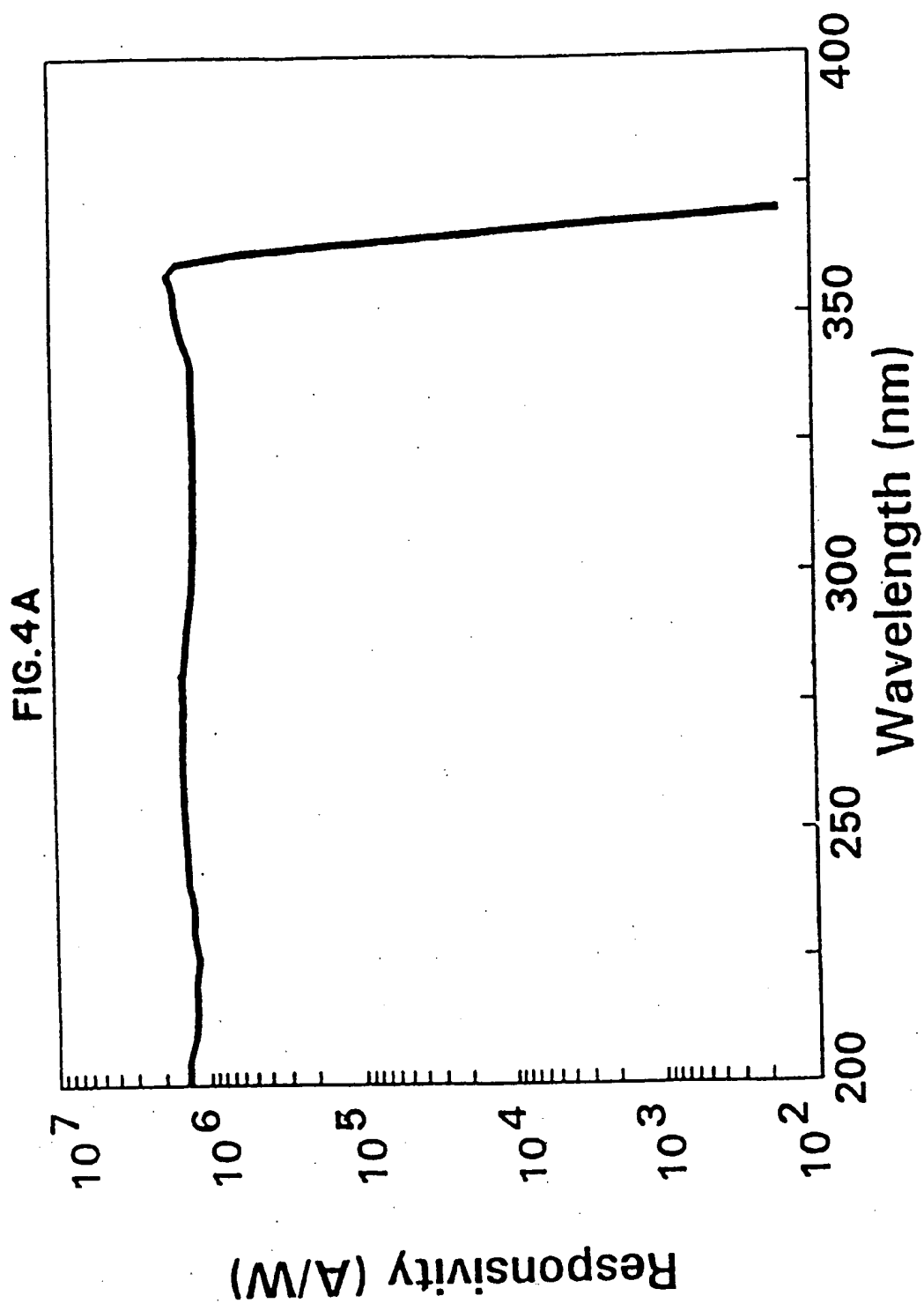


FIG. 3





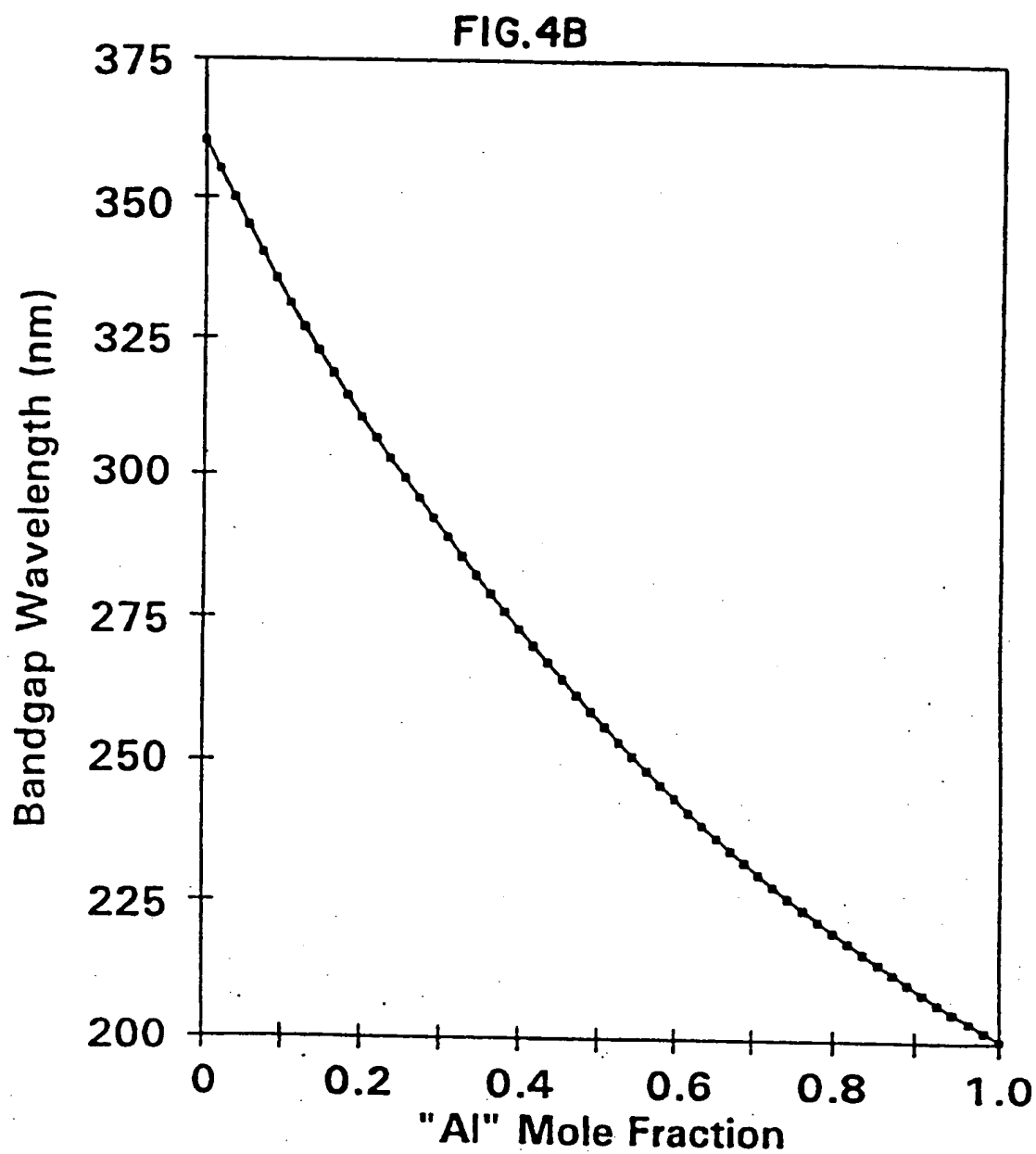
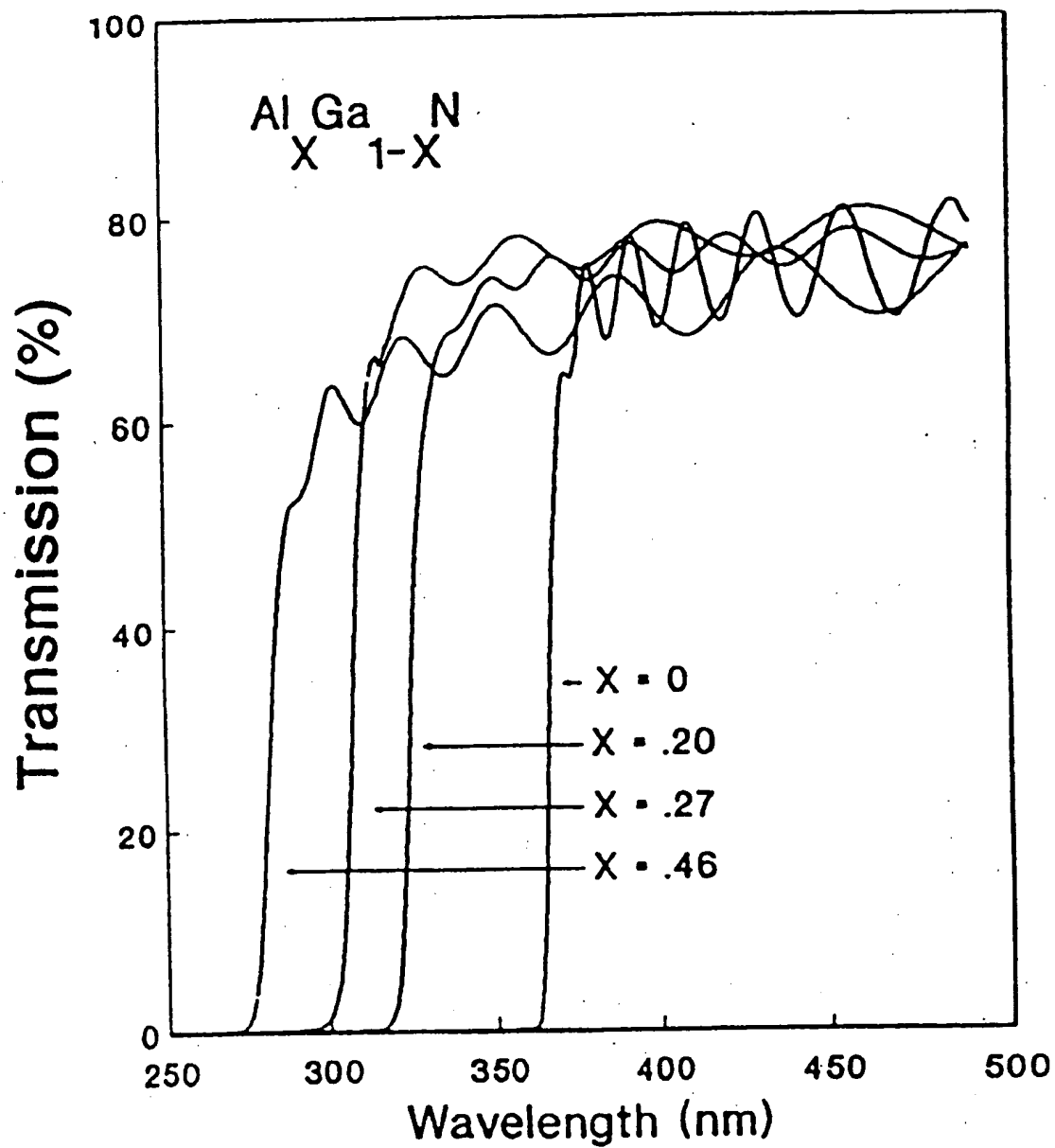


FIG. 4C



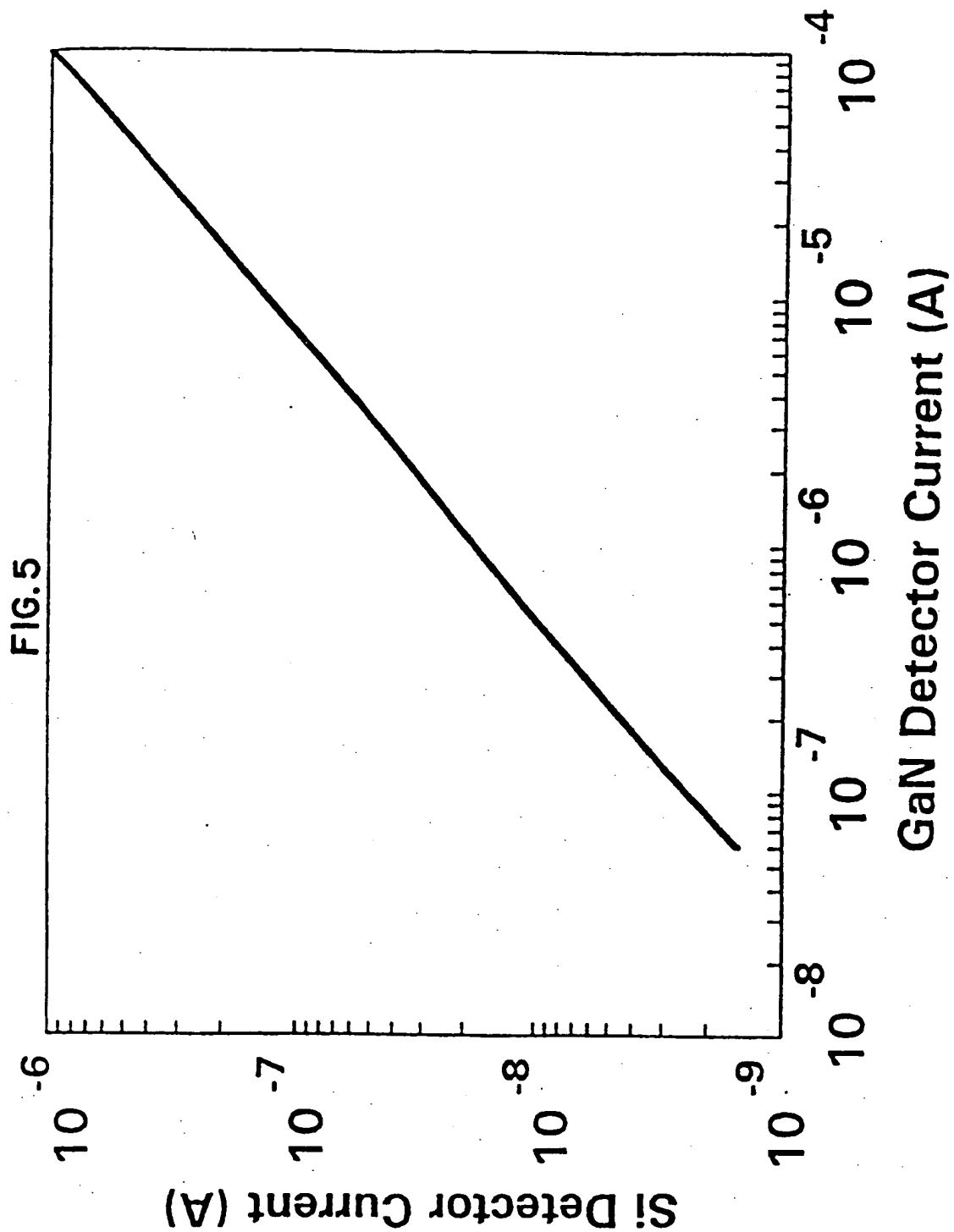
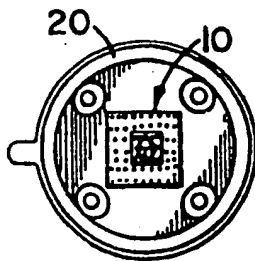
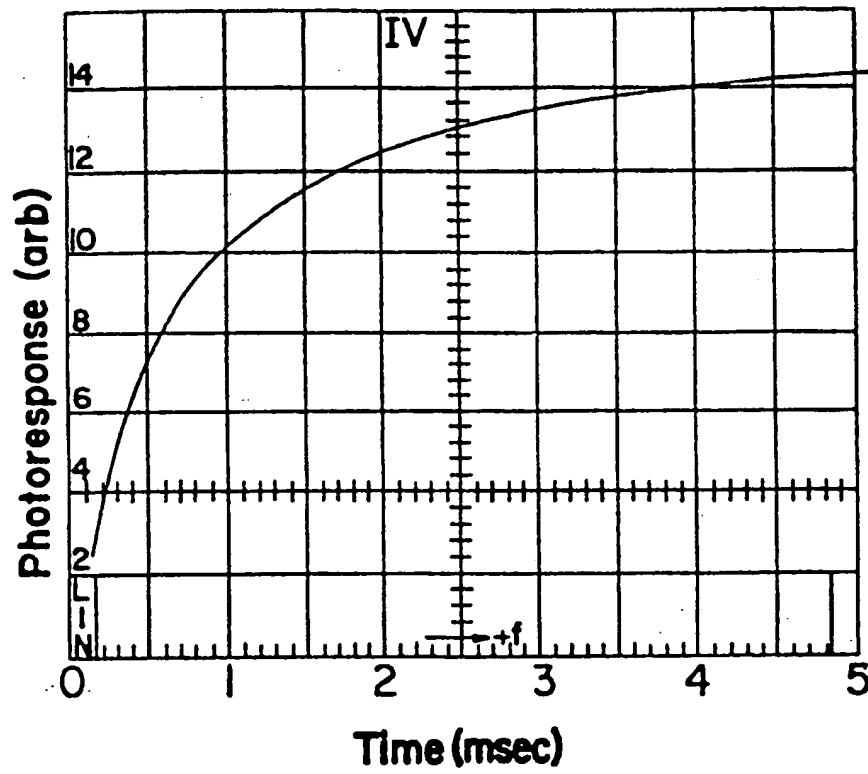
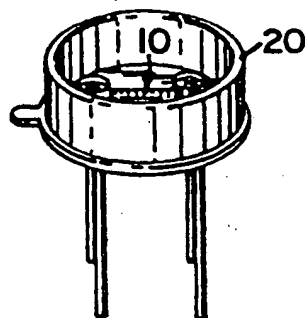


FIG. 6**FIG. 7****FIG. 8**

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 93/05448

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ⁴ According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁵ : H 01 L 31/0304, H 01 L 27/14		
II. FIELDS SEARCHED <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Minimum Documentation Searched ⁷</div> <div style="display: flex; justify-content: space-between;"> <div style="width: 30%;">Classification System</div> <div style="width: 70%;">Classification Symbols</div> </div> <div style="border-top: 1px solid black; border-bottom: 1px solid black; padding: 5px 0;"> IPC⁵ : H 01 L 27/00, H 01 L 31/00 </div> <div style="border-top: 1px solid black; border-bottom: 1px solid black; padding: 5px 0; text-align: center;"> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁶ </div>		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁸		
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4 614 961 (KHAN et al.) 30 September 1986 (30.09.86), claims 1-3; abstract (cited in the application). --	1-10
A	US, A, 4 616 248 (KHAN et al.) 07 October 1986 (07.10.86), claims 1-4 (cited in the application). --	1-10
A	US, A, 5 093 576 (EDMOND et al.) 03 March 1992 (03.03.92), claims 1,14,18; fig. 3. ----	1,2
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
06 October 1993		23. 10. 93
International Searching Authority		Signature of Authorized Officer
EUROPEAN PATENT OFFICE		PUSTERER e.h.

ANHANG

zum internationalen Recherchen-
bericht über die internationale
Patentanmeldung Nr.

ANNEX

to the International Search
Report to the International Patent
Application No.

ANNEXE

au rapport de recherche inter-
national relatif à la demande de brevet
international n°

PCT/US 93/05448 SAE 76139

In diesem Anhang sind die Mitglieder
der Patentfamilien der im obenge-
nannten internationalen Recherchenbericht
angeführten Patentdokumente angegeben.
Diese Angaben dienen nur zur Unter-
richtung und erfolgen ohne Gewähr.

This Annex lists the patent family
members relating to the patent documents
cited in the above-mentioned inter-
national search report. The Office is
in no way liable for these particulars
which are given merely for the purpose
of information.

La présente annexe indique les
membres de la famille de brevets
relatifs aux documents de brevets cités
dans le rapport de recherche inter-
national visé ci-dessus. Les renseigne-
ments fournis sont donnés à titre indica-
tif et n'engagent pas la responsabilité
de l'Office.

Im Recherchenbericht angeführtes Patentdokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
US A 4614961	30-09-86	DE C0 3581998	11-04-91
		EP A2 177918	16-04-86
		EP A3 177918	16-09-87
		EP B1 177918	06-03-91
		JP A2 61091977	10-05-86
US A 4616248	07-10-86	EP A2 202637	26-11-86
		EP A3 202637	21-01-87
		JP A2 61267374	26-11-86
US A 5093576	03-03-92	DE A1 4208172	17-09-92
		JP A2 5067803	19-03-93

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